CHAPTER 1

INTRODUCTION

1.1 Overview

Nowadays, applications involving robots have gained momentum due to their functionality and reliability when completing certain tasks as compared to human. These advantages have attracted many researchers to dedicate themselves into this area of research. One of the many types of research is the two-wheeled balancing robot.

This two-wheeled balancing robot has the exact behaviour of the inverted pendulum system which is known for its nonlinear and unstable system. The only difference between these two systems is the capability to freely move around for the two-wheeled balancing robot. Basically, the robot consists of two driving wheels which attached on each side of the robot chassis. These two wheels will be controlled by two dc motors that are coupled to a planetary gearbox as their actuator. Just as the inverted pendulum, this robot will balance itself by controlling the rotation of the wheels or in other words the rotation of the dc motors. This can be achieved by controlling the amount of voltages that applied to the dc motor.

This robot has three degrees of freedom (3-DOF) where it is able to rotate around the z-axis or pitch, a movement described by the angle θ with the corresponding angular velocity $\dot{\theta}$. The linear movement of the robot is characterized by the position x and the speed $\dot{x}$. Additionally, the vehicle also able rotates around its vertical axis or yaw with the associated angle δ and angular velocity $\dot{\delta}$. As described in Grasser *et al.* (2002), three types of disturbances are applied to the robot. One of the disturbances is applied to the centre gravity of the robot while the other two are applied to the centre of both left and right wheels. These disturbances will indicate the movement made by the driver on his seat as described in the paper.

In this thesis, two references are chosen as its main guidance. Based on these two references, the mathematical model of the two-wheeled balancing robot will be derived and then a Proportional Integral Sliding Mode Control as described in Sam (2004) will be designed in order to control the system.

1.2 Objective

The objectives of this research are as follows:

1. To formulate a complete mathematical model in state-space form of a two-wheeled balancing robot.

2. To control the robot focusing only on balancing using Proportional Integral Sliding Mode Control (PISMC) approach. The theoretical verification of the controller on its stability and reachability will be accomplished by using Lyapunov's second method.

3. To simulate the mathematical model of the two-wheeled balancing robot using MATLAB/Simulink in order to validate the derived controller.

4. To compare the performance of the Proportional Integral Sliding Mode Control with Statefeedback controller.

1.3 Scope of Project

The work undertaken in this project is limited to the following aspects:

1. The mathematical model of the two-wheeled balancing robot is derived based on Grasser *et al.* (2002) and Ooi (2003).

2. The Proportional Integral Sliding Mode Control (PISMC) will be designed as described in Sam (2004).

3. Simulation work using MATLAB/Simulink as a platform to prove the effectiveness of the designed controller.

4. Comparison results between the Proportional Integral Sliding Mode Control with Statefeedback controller.

1.4 Research Methodology

The research work is undertaken in the following four developmental stages:

1. The development of mathematical model for two-wheeled balancing robot.

2. The design of a Proportional Integral Sliding Mode Control.

3. Perform simulation for the Proportional Integral Sliding Mode Control in controlling the two-wheeled balancing robot.

4. Compare of performances between the Proportional Integral Sliding Mode Control with the Statefeedback controller.

1.5 Literature Review

The research on two-wheeled balancing robot has gained momentum over the last decade due to the nonlinear and unstable dynamics system. Various control strategies had been proposed by numerous researchers to control the two-wheeled balancing robot such that the robot able to balance itself. In this chapter, the previously done control approaches will be briefly discussed.

Grasser *et al.* (2002) had built JOE, a prototype of a revolutionary two-wheeled vehicle. The main objective of this vehicle is to balance its driver on two coaxial wheels. Each of the coaxial wheels is coupled to a dc motor. Due to its configuration with two coaxial wheels the vehicle is able to do stationary U-turns. The vehicle is controlled by applying a torque to the corresponding wheels. A control system, made up of two decoupled state space controllers, pilots the motors in order to ensure the system will always stay in equilibrium. The control system that was implemented into this system is a Statefeedback controller using pole-placement method. Three types of disturbances that indicate the movement made by the driver were also included into the system.

As a final year project student Ooi (2003) had discussed the development of a two-wheeled balancing autonomous robot based on the inverted pendulum model. The system is built as a platform to investigate the use of a Kalman filter for sensor fusion. The discussion examines the suitability and evaluates the performance of a Linear Quadratic Regulator (LQR) and a pole-placement controller in balancing the system. The LQR controller uses several weighting matrix to obtain the appropriate control force to be applied to the system while the pole-placement requires the poles of the system to be placed to guarantee stability. As the robot will be moving about on a surface, a Proportional-Integral-Derivative (PID) controller is implemented to control the trajectory of the robot.

Salerno and Angeles (2004) have made a report on a control of semi-autonomous two-wheeled mobile robots undergoing large variations of payload. These robots which being underactuated, poses some challenges when resorting to a simple controller. The latter being a linear controller, its robustness with respect to model uncertainty was investigated. A time-domain analysis was conducted in order to investigate the robustness of the foregoing controller with respect to parametric and unmodeled dynamics uncertainty. In this paper, a controller which is designed by a dominant second-order pole-technique is proved to be fragile with respect to unmodeled dynamics uncertainty. Thus, a novel controller based on Linear Quadratic Regulator (LQR) is designed for robustness with respect to the model-uncertainty.

Pathak *et al.* (2005) has analyzed the dynamic model of a wheeled inverted pendulum from a controllability and feedback point of view. The dynamic model of the underactuated system is derived with respect to the wheel motor torques as its inputs by taking the nonholonomic no-slip constraints into considerations. The partial feedback linearization of the system is obtained based on the results of the accessibility condition and the maximum relative degree of the system. The resulting equations are used to design two novel controllers of which one of them is a two-level velocity controller used for tracking vehicle orientation and heading speed set-points, while controlling the vehicle pitch. The other controller which is also a two-level controller used to stabilize the vehicle’s position to the desired set-point, while ensuring the pitch is bounded between specified limits.

Shiroma *et al.* (1996) have discussed the cooperative transportation of an object by two or more wheeled inverted pendulum robot. This task requires each robot to exert an appropriate force to support and move the object, to move along the object and to maintain its attitude. A Statefeedback controller using pole-placement method is implemented into this system in order for the robots to cooperate among themselves.

1.6 Thesis Layout

Chapter 2 deals with the mathematical modelling of the two-wheeled balancing robot. The formulation of the integrated dynamic model of this robot will be presented in detail. The modelling will be separated into three subsystems which are the modelling of the dc motor, the wheels of the robot and the chassis of the robot. These obtained equations will be integrated to form a complete state space representation of the system.

Chapter 3 presents the controller design using Proportional Integral Sliding Mode Control. This controller will be designed based on the Ph.D. Thesis of Sam (2004).

Chapter 4 discusses the simulation results. The performance of the Proportional Integral Sliding Mode Controller is evaluated by simulation study using MATLAB/Simulink. For comparison purposes, the simulation study of Statefeedback controller using pole-placement technique is also presented.

Chapter 5 summarizes the works undertaken. Recommendations for future work of this project are presented at the end of the chapter.